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Development of a Small Solar Power Generation System based on Thermoelectric Generator

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Abstract

Attentions have been paid to wide use of the natural energy while problems such as depletion of the fossil energy, control of greenhouse gases and risk caused by atomic power are faced. In this paper, we aim to realize a small solar power generation system by using solar heat based on thermoelectric generation principle. During the research, firstly, the amount of solar radiation at Fukuroi area where our university is located is calculated. Secondly, a small parabolic collector is used to collect the light and the heat. Thirdly, a thermoelectric generator is designed and manufactured inside which 4 Petier modules are employed. Then, by amounting the thermoelectric generator to the focus part of the parabolic collector, an experiment testing the electricity generation performance of the solar power generation is carried out. It is found that the open voltage reaches 3.9V when the temperature difference is 40 degree.

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1. Introduction

As mankind are facing energy and environmental problems caused by rapid industrialization all over the world and huge amount of fossil fuel consumed, researches on clean energies such as biomass, solar,

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wind and so on have been widely conducted and reported. In regard with solar energy, using sunshine to generate electricity is becoming more important and attractive because it is clean and inexhaustible. Usually methods of electricity generation based on solar energy are grouped into solar light utilization and solar heat utilization. For solar light utilization, when a PV is irradiated by solar light, the solar energy will be converted into electric energy. There are several types of PV that are being used such as monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Among them, though silicon PV has been employed at a commercial level, solar photovoltaic array capacity factors are typically under 25%, which is lower than many other industrial sources of electricity, so the electricity generation efficiency and cost have not yet met the needs demanded by the society.

Recently, more attentions have been paid to the study of employing solar heat to generate electricity due to its potentially high efficiency. In Japan, Tanaka has described a method of increasing system availability on the basis of the experimental results obtained by the operation of these systems. As a result, it is shown that the operating method and the capacity of the heat storage unit have an influence on system availability[1]. Also Fujihara proposed an optimum method for deciding best heat-collecting temperature based on a their simulation results[2].

In this paper, in order to establish a small type solar power generation system based on the thermoelectric generator, firstly, the amount of solar radiation at Fukuroi area where our university is located is calculated. Secondly, a small parabolic solar collector is used to collect the light and the heat. Thirdly, a thermoelectric generator is designed and manufactured inside which 4 Petier modules are employed. Then, by mounting the thermoelectric generator to the focus part of the parabolic solar collector, an experiment testing the electricity generation performance of the solar power generation is carried out.

2. Theoretical background

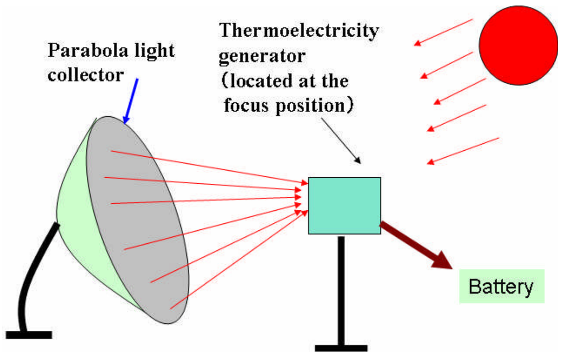

Fig. 1 Concept of solar power generation system based on thermoelectric generator

2.1. Concept of solar power generation system

In Fig.1, the concept of solar power generation system based on thermoelectric generator is demonstrated. This system consists of the parabolic solar collector, the thermoelectric generator and the battery. When solar light is collected by the parabolic solar collector, it will be focused on the focus point where the thermoelectric generator is mounted. As one side of the thermoelectric generator is heated(hot side) while other side's temperature is kept lower(cool side), the temperature difference between the hot side and the cool side will cause the thermoelectric generator to generate the electricity. Finally, the electricity will be stored into the battery.

2.2 Theory of thermoelectric generation

Thermoelectric generation is based on Seebeck effect. Fig.2 shows Seebeck Effect. Assuming 2 different metals, say metal A and metal B, are connected to form a circuit. When one of the joint is located in the higher temperature atmosphere while the other joint is located in the lower temperature atmosphere, then the electromotive force V inside the circuit is expressed by

$$V = \pi \Delta T \quad (1)$$

Where π is Seebeck coefficient.

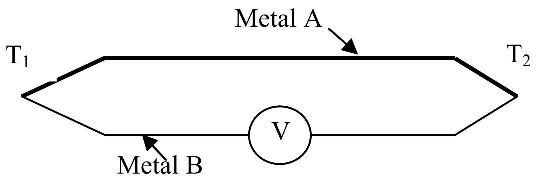

Fig.2 Thermoelectric generation based on Seebeck effect

3. Calculation of solar energy collected

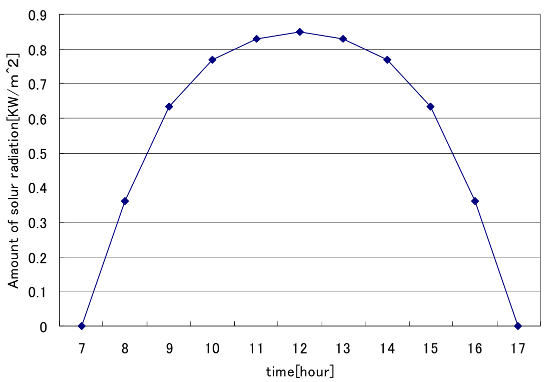

Fig.3 Amount of solar radiation collect at Fukuroi area

In order to calculate the normal direct solar radiation I_{DN} in Fukuroi area where our university is located, the following equation is used.

$$I_{DN} = I_o P^{\frac{1}{\sinh}} \quad (2)$$

Where I_0 is the solar constant[kW/m^2], P is transmissivity and h is sun elevation [°], respectively.
And

$$\sinh = \sin\varphi \sin\delta + \cos\varphi \cos\delta \quad (3)$$

Here φ is the latitude [°] and δ is the apparent declination [°] and t is hour angle [°], respectively.

By inserting all the parameters of Fukuroi area in the Eqs.2-3, one example of the calculated results is shown in Fig.3. It is found that from 7:00-17:00, the amount of solar radiation collect at Fukuroi tends to be a quadric curve while at noon it reaches the maximum value of 820 W/m^2.

Since it is decided to use a parabolic solar collector, it is necessary to calculate all the energy collected by a parabolic solar collector. Assuming that the open area of the parabolic solar collector is $A = 0.19$ [m^2] and reflectance of its surface is $R = 0.94$, then the energy collected by the parabolic solar collector is expressed by the following equation.

$$Q = AI_{DN}R \qquad (4)$$

Base on the Eqs.2-4, the heat collected by the parabolic solar collector is calculated and illustrated in Fig.4. It can be seen that the amount of energy

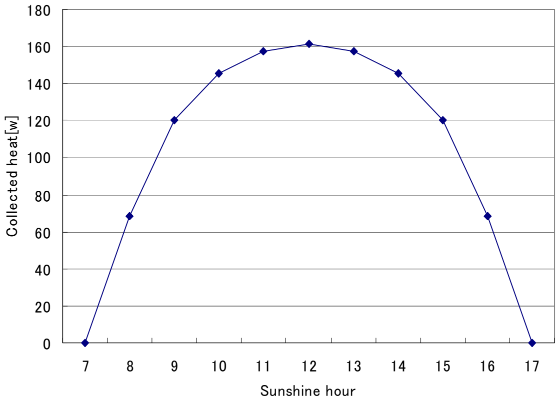

Fig.4 Amount of energy collect by parabolic solar collector

collected by the parabolic solar collector is changing with the shift of the sunshine hour. Similar to the result of amount of solar radiation collect at Fukuroi area, at noon, the energy collected the parabolic solar collector reached the maximum value of 162W.

4. Experiment

In order to test the possibility of thermoelectric generation by employing the collected solar energy, a series of experiment including temperature measurement and electricity generation experiment were conducted. After some element parts of the experiment system are introduced, temperature experiment and electricity generation experiment will be described.

4.1 Parabolic solar collector

In Fig.5, the parabolic solar collector is shown. The depth, major axis and minor axis of the parabolic solar collector is 40mm, 530mm and 460mm, respectively. The open area is 0.19 m^2.

In order to enhance the reflectivity, the mirror film coated with silver(3M, Solar Mirror Film) is pasted on the parabolic solar collector. The reflectivity is said to be 0.94.

Fig.5 Parabolic solar collector

4.2 Themoelectric generator

Solar thermoelectric generator is shown in Fig.6. It has a “sandwich” structure. The first layer of aluminum is the high temperature side where the solar energy is to be absorbed. The second layer is the Seebeck module. In this study, instead on using Seebeck module, 4 pairs of

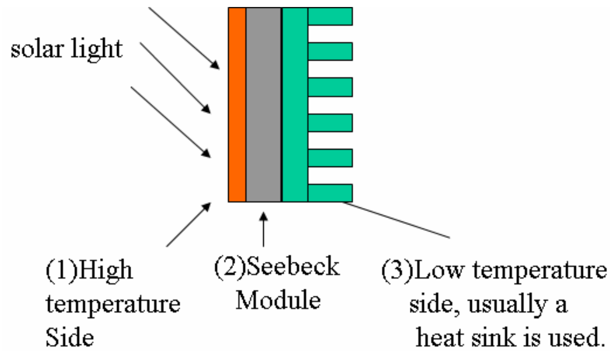

Fig.6 Solar thermoelectric generator

Peltier module are employed. The third layer is low temperature side. Here a heat sink of aluminum is used to release the heat flowing from the high temperature side to the low temperature side inside the Peltier module to the surroundings

The assembled thermoelectric generator is show in Fig.7. The dimension of it is 110×110×74 mm.

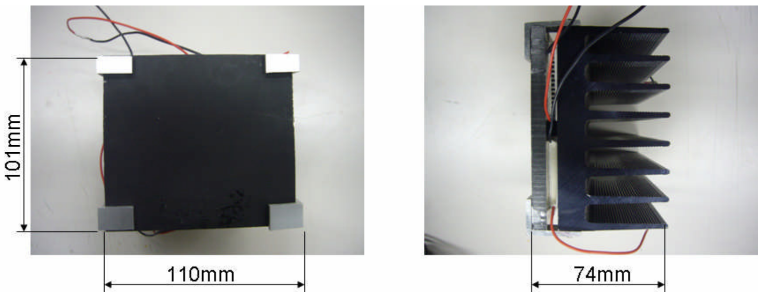

Fig.7 Assembled thermoelectric generator

4.3 Temperature measurement

Experiment system for temperature measurement is shown in Fig.8. After the solar light is collected by the parabolic solar collector, it is concentrated on the focus part where an array of thermocouples is prepared. All the temperature data are recorded by a data logger.

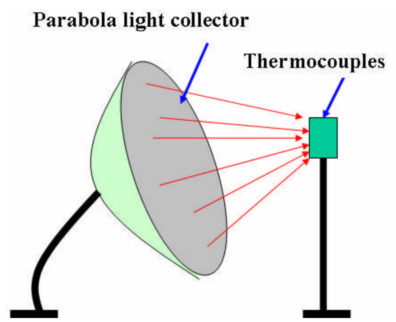

Fig.8 Experiment system of temperature measurement

4.4 Electricity generation

Experiment system for electricity generation temperature measurement is shown in Fig.9. After the solar light is collected by the parabolic solar collector, it is concentrated on the focus part where the high temperature side is mounted. In order to prevent convection heat transfer loss, an acrylic box(Fig.10) is used to cover the high temperature side. Meanwhile, the high temperature side is painted with dark color to increase the absorptivity. Output from the thermoelectric generator is measured by a voltmeter, then, together with the temperature data measured at the same time are recorded by a data logger.

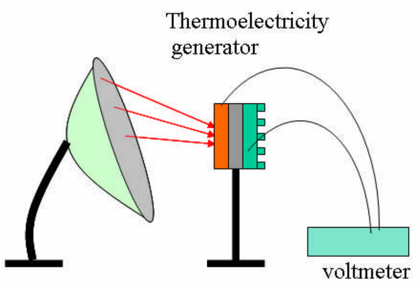

Fig.9 Experiment system of electricity generation

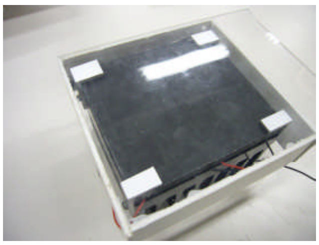

Fig.10 Thermoelectric generator covered with acrylic box

5. Result and discussion

One example of the temperature experimental result is shown in Fig.11. The temperature of the high temperature side rises as the sunshine hour moves from 10:00 to 11:00, then, almost keeps unchanged until 12:00, and finally begins to decrease while the temperature of the low temperature does not change too much. The temperature difference showed the same trend as the temperature of the high temperature side. It is found that the maximum temperature difference reached 202 degree, which is possible for thermoelectric generation.

In Fig.12, temperature of the thermoelectric generator is shown. The temperature at high temperature reached the maximum value of 100 degree while the temperature at low temperature side is around 20 degree.

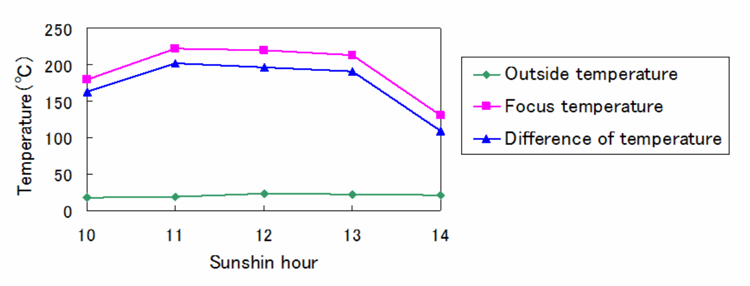

Fig.11 Thermoelectric generator covered with acrylic box

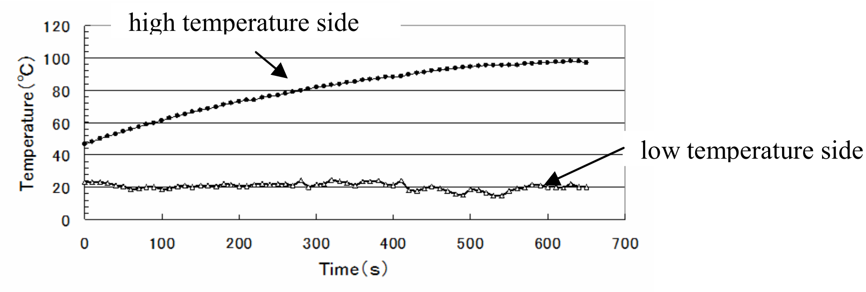

Fig.12 Temperature data obtained from thermoelectric

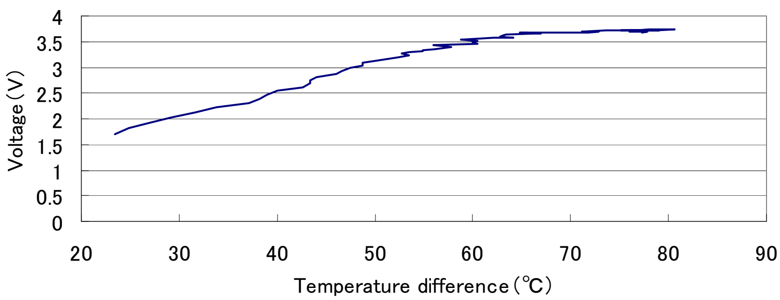

Fig.13 Electricity generation results

The reason why the highest temperature value of 202 degree could not be reached is that the aluminum plate with higher thermal capacity is used. Hence it can not react quickly when solar energy is absorbed.

In Fig.13, the electricity generation result is shown. It is found that as the temperature difference increases, the open electricity voltage will become larger. The maximum voltage obtained is almost 3.8 V.

6. Conclusion

A small solar heat electricity generation system base on thermoelectricity theory was developed. By carrying out a serial of calculations and experiments，it was confirmed that the maximum temperature reached 202 degree and the maximum open voltage was about 3.8 V.

Acknowledge

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